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Wavelength conversion based on cross-phase modulation in a semiconductor Mach-Zehnder modulator

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Abstract: Wavelength conversion based on cross-phase modulation in a reversely biased semiconductor Mach-Zehnder modulator is proposed and successfully demonstrated in a commercial device. The converted signals exhibit extinction ratio >13 dB and penalty <1.5 dB at 10Gb/s for both NRZ and RZ formats.

1. Introduction:

Wavelength converters are key components for future advanced optical networks, and several technologies have been used to realize wavelength conversion: opto-electronic conversion, optical wave mixing including four wave mixing and difference frequency generation, optically controlled gating including cross-gain and cross-phase modulation in semiconductor optical amplifiers [1,2]. Recently wavelength conversion based on cross-absorption modulation in saturated electroabsorption modulators (EAM) has been reported, showing high conversion speed up to 40Gb/s, large wavelength range and regenerative capability [3-5]. However, cross-absorption modulation in EAMs requires high input optical power, which restricts conversion to RZ format with short optical pulses (~10 ps) [3,4], and no wavelength conversion of NRZ format has been reported so far using cross-absorption modulation.

In this paper, we explore phase modulation in a reversely biased semiconductor Mach-Zehnder structure and demonstrate wavelength conversion in a commercial InGaAsP Mach-Zehnder modulator (MZM) originally designed as a 10Gb/s transmitter. The converted signals exhibit an extinction ratio better than 13 dB and a penalty less than 1.5 dB at 10Gb/s for both NRZ and RZ formats.

2. Principle and basic characteristics:

Fig. 1(a) shows the schematic diagram of the wavelength converter; the core part is a multiple quantum well (MQW) based InGaAsP Mach-Zehnder modulator. The MZ modulator, which is originally designed as a 10Gb/s transmitter, is fabricated by low-pressure metal organic chemical vapor deposition (MOCVD), and has an active length of the MZ arms of 600 μm [6].

An intensity modulated input signal with wavelength λ_i is coupled into the asymmetrically biased MZM through an optical circulator, and travels in two arms of the MZM. One of the MZM arms is reversely biased while the other arm is applied a 0 volt bias. The input optical signal in the reversely biased arm is partly absorbed and generates carriers, and the carriers further change the index of that arm. Since the carriers generated by the input signal is roughly proportional to the optical intensity, the intensity modulation of the input signal is transferred into a phase modulation in this arm. The input optical signal in the non-biased arm induces less index change since less light is absorbed. A CW probe light at λ_c , counter-propagating with the input signal, experiences a phase difference between the two arms, and hence becomes intensity modulated at the output of the MZM. The modulated light with wavelength λ_c , i.e., the converted signal, is guided out through the circulator.

An optical isolator is put between the DFB laser and the MZM to prevent the input light from going into the laser. The MZM, DFB laser and optical isolator shown in the dashed frame of Fig. 1(a) are integrated into a compact fibre-pigtailed package together with a wavelength locking scheme. Fig. 1(b) shows a photograph of the packaged device.

Fig. 2 shows the static characteristics of the wavelength converter under different bias conditions. The wavelengths of the CW probe-light and the input signal are 1557.36 nm and 1550.00 nm, respectively, in all

experiments. When the left bias is set to -4.2V and right bias to 0V, the output power of the probe light increases as the input power increases, and the output power changes 10 dB when the input power increases from 5.8 dBm to 13.8 dBm. This indicates a non-inverted wavelength conversion capability with an improvement of the signal extinction ratio. When the right bias is set to -4.47 V and the left bias to 0 V, the output power of the probe light decreases as the input power increases. This conversion possibility clearly shows the difference between cross-phase modulation and cross-absorption modulation where the output power always increases as the input power increases.

3. Wavelength conversion of 10Gb/s NRZ

The wavelength converter is used to convert a 10Gb/s NRZ signal, which has not been reported using cross-absorption modulation in an EAM. The 10 Gb/s optical NRZ signal is generated by a Lithium Niobate external modulator with a pattern length of $2^{31}-1$. After being amplified to an average power of 13.8 dBm, the signal is fed into the wavelength converter. The converted eye-diagrams and waveforms detected by a fast photo detector are shown in Fig. 3.

From Fig. 3(a), we can see that the converted 10Gb/s NRZ signal has a wide open eye-diagram and the extinction ratio is better than 13 dB, which is optimised by the bias setting. From Fig. 3(b) and (c), we can see that the converted signal can have either inverted (b) or non-inverted (c) polarity in comparison with the input signal by changing the bias settings of the MZ, which again confirms the phase modulation effect in the MZ modulator. Bit-error-rates (BERs) of the converted signal and the input signal measured using an optically pre-amplified receiver are shown in Fig. 4. Power penalties less than 1.5 dB at BER= 10^{-9} can be found from Fig.4.

4. Wavelength conversion of 10Gb/s RZ

The wavelength converter is also used to convert a 10Gb/s RZ signal. The 10Gb/s optical RZ signal is obtained by externally modulating the optical light source with an electrical RZ signal using the Lithium Niobate modulator [7]. The FWHM pulse-width of the 10Gb/s RZ optical signal is about 40 ps. The converted signal is detected using the same photo detector. Fig. 5 shows the eye-diagrams of input signal in (a) and converted signal in (b). Comparing the two eye-diagrams, no obvious pulse-broadening after wavelength conversion can be found, which indicates a fast conversion feature of the device. The extinction ratio of the converted signal is also better than 13 dB. Measured BER curves of input signal and converted signal are shown in Fig. 6 using the same receiver, and power penalties less than 1.5 dB at BER= 10^{-9} can be found.

5. Conclusion

Wavelength conversion based on cross-phase modulation in a reversely biased semiconductor MZ modulator has been proposed and successfully demonstrated at 10Gb/s for both NRZ and RZ formats using a compact wavelength stabilised commercially available 10Gb/s transmitter. The experimental results show that wavelength conversion based on cross-phase modulation in reversely biased semiconductor MZ modulators can be realized at high speed for both NRZ and RZ.

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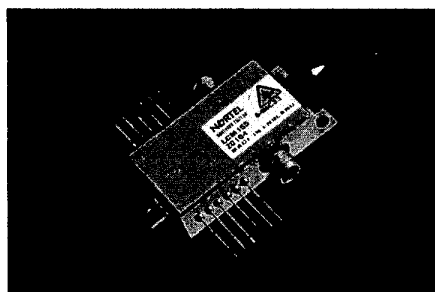
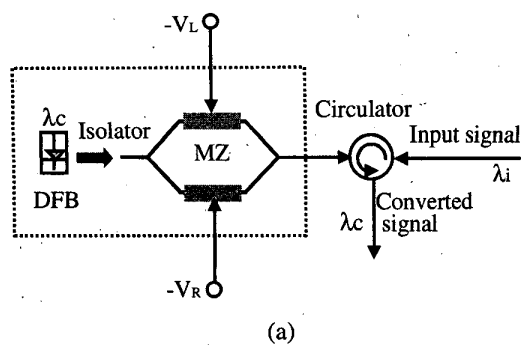


Fig. 1. Schematic diagram (a) and photograph (b) of the wavelength converter. MZ: InGaAsP Mach-Zehnder modulator.

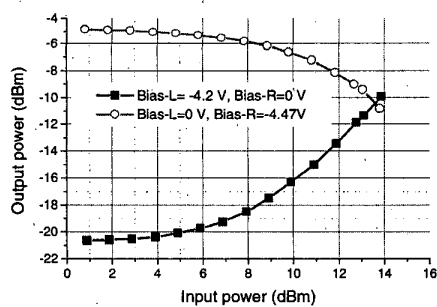


Fig. 2. Static characteristics of the wavelength converter.

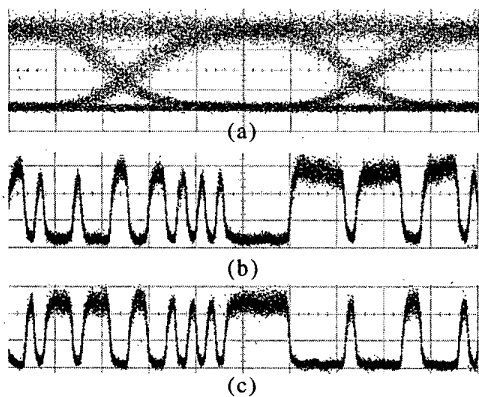


Fig. 3. Eye-diagrams (a) and waveforms (b, c) of the converted signals of 10Gb/s NRZ. (b) Inverted conversion. (c) Non-inverted conversion.

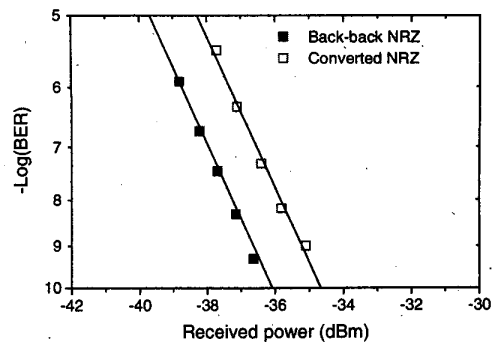


Fig. 4. BER curves of wavelength conversion of 10Gb/s NRZ signal.

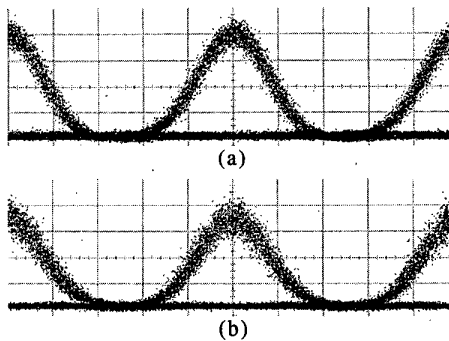


Fig. 5. Eye-diagrams of input signal (a) and converted signal (b).

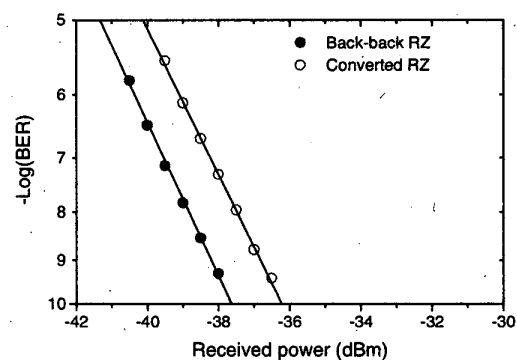


Fig. 6. BER curves of wavelength conversion of 10Gb/s RZ signal.